

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL OF MARINE AND ATMOSPHERIC SCIENCES

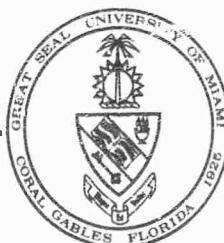
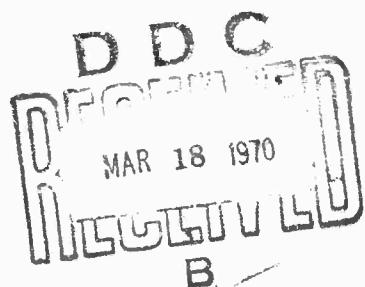
AD702469

RADAR SEA STATE ANALYZER

FINAL REPORT
DECEMBER 1969

by
G. F. Andrews and H. W. Hiser

Prepared under Contract N00019-68-C-0393 for the
Naval Air Systems Command, Department of the Navy



This document has been approved
for public release and sale; its
distribution is unlimited.

MIAMI, FLORIDA 33149

38

UNCLASSIFIED

Radar Meteorological Laboratory
ROSENSTIEL SCHOOL OF MARINE AND ATMOSPHERIC SCIENCES
UNIVERSITY OF MIAMI
MIAMI, FLORIDA 33149

RADAR SEA STATE ANALYZER
(15 May 1968 to 15 August 1969)

FINAL REPORT
December 1969

by

G. F. Andrews and H. W. Hiser

Prepared under Contract N00019-68-C-0393 for the
Naval Air Systems Command, Department of the Navy

B8765-1

F. G. Walton Smith
Dean

ML 70012

UNCLASSIFIED

ABSTRACT

The theory and description of a Radar Sea State Analyzer are presented. Installation, operation, adjustments, and readout interpretation instructions are also included. The instrument is the product of three years of research to obtain sea state information by using an existing radar as the remote sensor. This device is an attachment to the radar and examines the "sea return" signals at a selected range within the limits of the radar horizon. The outputs are available in digital and analog form. It is small in size and uses modern semi-conductor techniques, integrated circuits, etc. to achieve stability, accuracy and reliability.

TABLE OF CONTENTS

	<u>PAGE NO.</u>
ABSTRACT	i
TABLE OF CONTENTS	ii
LIST OF FIGURES	iii
1.0 INTRODUCTION	1
2.0 SYSTEM CONCEPTS; RADAR REMOTE SENSING	2
2.1 Theoretical Concepts	2
2.2 System Development	3
3.0 THEORY OF OPERATION - SEA STATE ANALYZER	8
3.1 Technique	8
3.2 Electronic Circuit Functions	9
3.3 Circuit Diagrams	9
4.0 INSTALLATION	20
4.1 Inputs	20
4.2 Outputs	20
5.0 OPERATION AND ADJUSTMENTS	22
5.1 Digital Wave Period	22
5.2 Control Panel Functions	22
5.3 Adjustment and Operation Procedure	24
5.3.1 Preliminary Radar System Adjustments	24
5.3.2 Analyzer Adjustments and Operating Procedure	24
6.0 INTERPRETATION OF READOUT	26
6.1 Digital Wave Period	26
6.2 Analog Chart Readout	26
7.0 BIBLIOGRAPHY AND REFERENCES	29

LIST OF FIGURES

<u>FIGURE NO.</u>		<u>PAGE NO.</u>
2.1	MAP SHOWING ALL OF THE AZIMUTHS AND SOME OF THE GATED SAMPLE AREAS INVESTIGATED	5
2.2	DATA SAMPLE USING RADAR ANTENNA WITH 3-DEGREE BEAMWIDTH	6
2.3	DATA SAMPLE USING RADAR ANTENNA WITH 2-DEGREE BEAMWIDTH	7
3.1	BLOCK DIAGRAM	10
3.2	DUAL REGULATOR	11
3.3	BUFFER AND LAMP DRIVER	12
3.4	SYSTEM CLOCK	13
3.5	10^4 DIVIDER	14
3.6	CONTROL LOGIC	15
3.7	SLOPE DETECTOR AND FILTER	16
3.8	GATE AND RELAY GENERATOR	17
3.9	SAMPLE-HOLD AND ANALOG DRIVER	18
3.10	REGULATOR CONTROL-LV POWER SUPPLY	19
4.1	RADAR SEA STATE ANALYZER	20
4.2	REAR VIEW OF ANALYZER	21
4.3	TOP INTERIOR VIEW OF ANALYZER	21
5.1	FRONT VIEW OF ANALYZER	23
5.2	FRONT VIEW, CONTROL PANEL EXPOSED	23
6.1	GRAPHICAL PRESENTATION OF THE THEORETICAL RELATIONSHIP BETWEEN WAVE LENGTHS, VELOCITIES, AND PERIODS IN DEEP WATER	27
6.2	ANALOG CHART RECORD	28

1.0 INTRODUCTION

This report gives the theory and description of a Radar Sea State Analyzer and provides installation, operation, adjustments, and readout interpretation instructions for it. This prototype instrument is an attachment for existing radar systems. It has been developed and tested during the latter part of a three-year research project devoted to the study of techniques for extracting sea state data from radar echoes from a rough sea surface. These echoes are known as "sea clutter" or "sea return". The objective was to remotely sense the state of the sea some distance from the radar out to the limits of the radar horizon.

During the first year of research, an extensive literature survey was made to supplement our knowledge of radar sea return that had been gained from several years of observations and photography. Concurrently, a recording and spectrum analysis system was developed to store and analyze both radar video and wave sensor data. During the second year, analysis of the data was performed, using both manual and automatic digital techniques. As results were achieved, new cases were stored and studied.

The instrument designed to perform this remote sensing function is small in size, and uses semi-conductor techniques, integrated circuits, etc. to achieve stability, accuracy, and reliability. It can significantly increase the potential utility of an existing radar at a nominal cost by providing information about the ocean. The outputs of the device are available in digital and analog form. Future possibilities include computer processing of these outputs in real-time to derive additional information such as long-period ground swells and trends in the state of the sea for operational applications.

2.0 SYSTEM CONCEPTS: RADAR REMOTE SENSING

2.1 THEORETICAL CONCEPTS

This instrument is the product of three years of research and development. During and since World War II, many investigators have studied radar sea return echoes usually with the objective of removing them from viewing scopes or to develop means for identifying other targets in their presence. The hypothesis of this project was that sea state conditions probably could be remotely sensed by radar observations of sea return.

The power returned from the sea surface is primarily a function of the average radar cross section of sea echo per unit area of the sea surface (σ^0), radar characteristics, and the angle of incidence of the radar beam on the sea surface. Goldstein in a book by Kerr [21] indicates that the target responsible for sea echo can always be resolved into a number of individual scatterers that can be treated as independent of each other. These scatterers may range in size from small spray droplets to large-scale surface waves or even a train of waves. Goldstein also states that the important quantity σ^0 is independent of many of the characteristics of the radar set but is a function of at least five parameters:

1. The angle that the incident ray makes with the horizontal.
2. Radar wavelength.
3. Direction of polarization of the radar energy.
4. State of the sea.
5. Azimuth relative to the wave pattern on the sea surface (that is, upwind or downwind, etc.)

Experiments have shown that σ^0 changes with the direction of the wind. If σ_u^0 denotes the upwind value of σ^0 , σ_d^0 the downwind value, and σ_c^0 the crosswind value, then: $\sigma_u^0 > \sigma_d^0 > \sigma_c^0$ for vertical polarization and $\sigma_u^0 > \sigma_c^0 > \sigma_d^0$ for horizontal polarization. The differences between σ_u^0 , σ_c^0 and σ_d^0 are of the order of 0 to 5 db, Beckmann and Spizzichino [36].

For small grazing angles, with which we are concerned, Davies and Macfarlane [39] observed a rapid increase of σ^0 as the ocean wave height increased, until a sort of "saturation" set in. At X-band, the saturation height has been observed to be about 2 or 3 feet, Skolnik [40], and as the radar wavelength increases, the saturation height increases. Other investigators, Boring, et.al. [18], have

observed sudden increases in σ^0 (as much as 10 db in a one-minute interval) for a sea with a 2-foot average wave height at the time of an abrupt increase in wind speed. Empirical formulas fitted to their data by Long, et.al. [12], indicate that for small grazing angles (less than 4°) σ^0 varies about as the cube of the wind speed for horizontal polarization of the radar energy and as the square of the wind speed for vertical polarization. The dependence on wave height was much weaker. Other observers, Schooley [56], have reported for horizontal polarization that " σ^0 is very approximately proportional to the local wind velocity squared". Long, et.al. [12] conclude that there may be a saturation effect with wind speed similar to the saturation effect with wave height. For example, σ^0 is less sensitive to a 5-knot change in wind speed at 25 knots than at 10 knots.

Our observations, Hiser and Andrews [54], [57], also show the non-linear increase of σ^0 with increasing wave height. A freshening sea shows a rapid increase in σ^0 up to a certain roughness or wave height. Beyond this, there is a less rapid increase of σ^0 with wave height. This complicates the problem of remotely measuring the wave height with radar.

2.2 SYSTEM DEVELOPMENT

For several years, we had made qualitative observations of radar sea return east of Miami in the Gulf Stream during periods of strong north and northeast winds. Winds from these directions are opposing the Gulf Stream current and have a long fetch region in which to produce high seas. Fortunately, the Underwater Acoustics Group in the Division of Ocean Engineering of this School had previously installed wind, wave height and other sensors at Fowey Rocks lighthouse 13 nautical miles southeast of our radar facility. Use of information from these assisted us greatly as we began quantitative sea-return measurements. The wave-height sensor is in deep water east of the lighthouse on the west side of the Gulf Stream.

An Ampex model VR-1500 video magnetic tape recorder was modified to permit storage of analog wideband video output from the UM/10-cm radar system when sea clutter was observed. This permitted post analysis of the data using various spectrum analysis techniques. The wave-height sensor data were brought by submarine cable and telephone line from Fowey Rocks lighthouse to our Laboratory where they were recorded in analog form on an auxiliary channel

of the Ampex video tape recorder. The axis of the radar beam was positioned at approximately $+0.5^\circ$ elevation above the horizontal and was held stationary on a particular azimuth, usually that of the lighthouse and sensors, while sea clutter video and wave-height sensor data were being tape recorded.

The radar is 10-cm wavelength, horizontally polarized, and provides a choice of a one or two microsecond pulse duration at a pulse repetition frequency of 300 pulses per second. The one-microsecond pulse duration was most often used for recording sea clutter video. This provided a sample depth in range of 150 meters. The antenna system in use during most of the project provided a 3-degree conical beam. At the range to the sensors this gave a beamwidth resolution of approximately 1300 meters on the sea surface. A new 12-ft diameter antenna was installed in 1968 and this provided a 2-degree conical beam for the 1968-69 data period. Results obtained with the new antenna agreed with those from the previous system.

Spectrum analysis was performed on the radar video data with equipment designed by Andrews [58] for all dates that were tape recorded. Usually, three range-gated samples of radar video were analyzed. The range gates were set to encompass 150 meters each and were usually positioned starting at 24.7, 25.0 and 25.3 kilometers respectively thus allowing 150 meters separation in range between each sampled area, Figure 2.1. The sample at 24.7 kilometers was approximately over the wave-height sensor. Illustrations of the analog chart readouts of spectrum analyzed video data from the gated sample areas are presented in Figures 2.2 and 2.3. The wave-height sensor data were read out from the tape onto these analog charts simultaneously with the radar data, insuring time synchronization of the data.

Mean wave periods were manually extracted from these charts of both radar and wave sensor data. In addition, automatic digital computations of period (P) and mean period (\bar{P}) were performed and printed on paper tape. The results of both the manual and automatic digital techniques showed that the radar indeed could provide average wave period to match the wave sensor readout with a high degree of confidence, Hiser and Andrews [57]. This was the basis for designing the computer to automatically read out wave period in units and tenths of seconds in the Radar Sea State Analyzer. From this period information, certain other interrelated wave parameters such as wave length and velocity can be determined. In addition, estimates of wave heights (within the constraints mentioned in Section 2.1) or, more precisely, trends of wave heights, can be made.

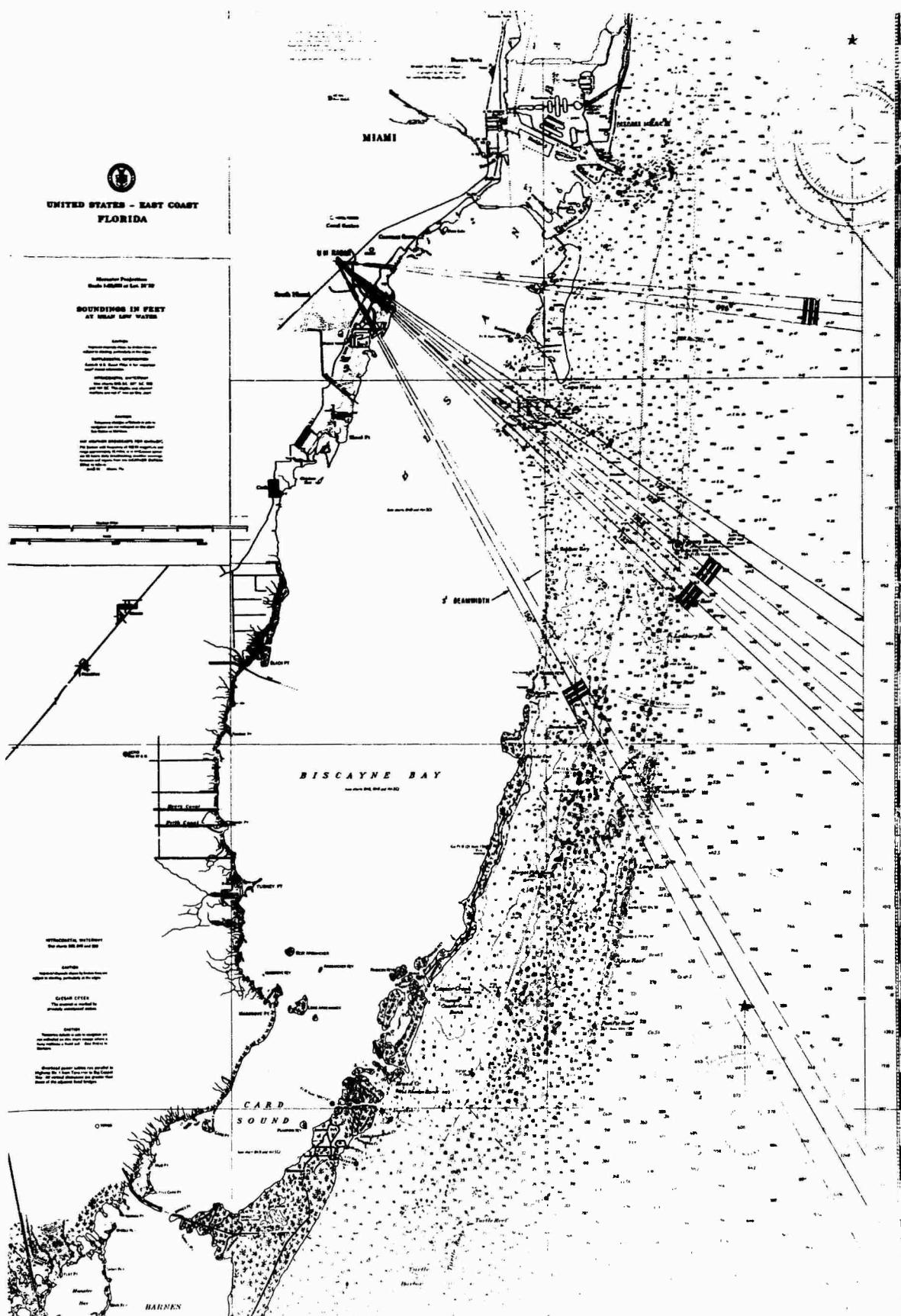
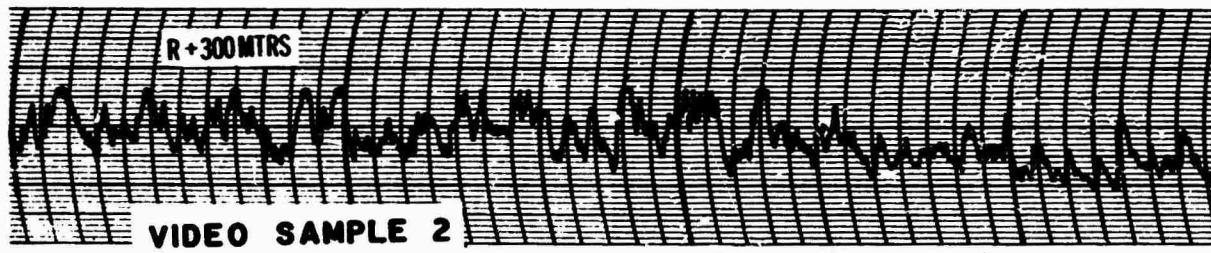
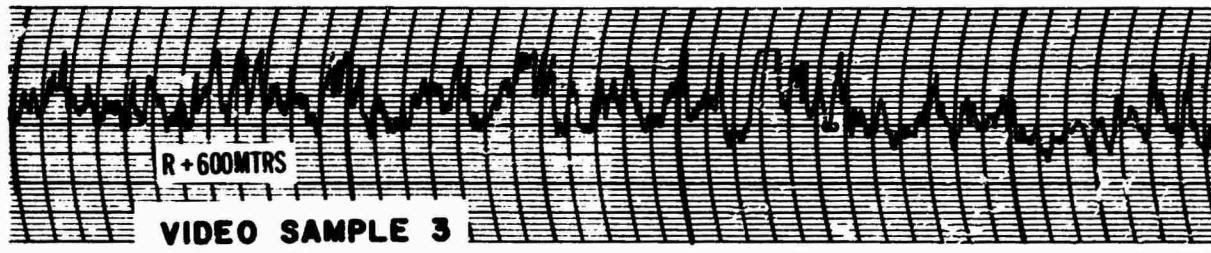


FIG. 2.1 - MAP SHOWING ALL OF THE AZIMUTHS AND SOME OF THE GATED SAMPLE AREAS INVESTIGATED



NOTE: 7-9 VIDEO PEAKS/MIN.



RADAR SEA CLUTTER VIDEO ANALYSIS B. JANUARY 1968



WAVES AVERAGE 3-4 FT., WIND ENE. 22-26KTS.

NOTE: 7-9 WAVE PEAKS/MIN.

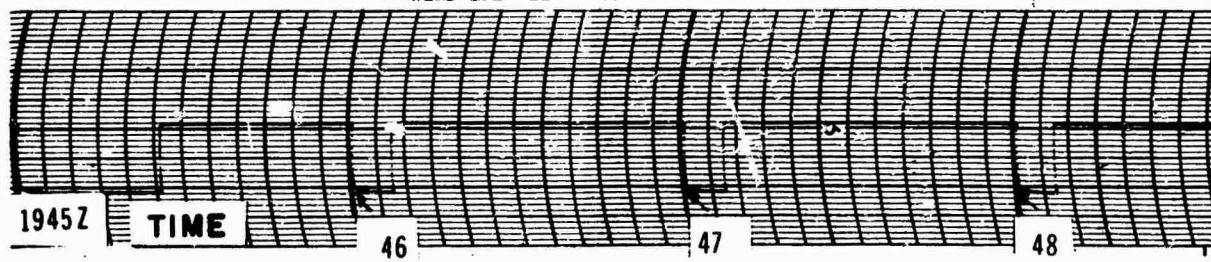


FIG. 2.2 - DATA SAMPLE USING RADAR ANTENNA WITH 3-DEGREE BREADTH

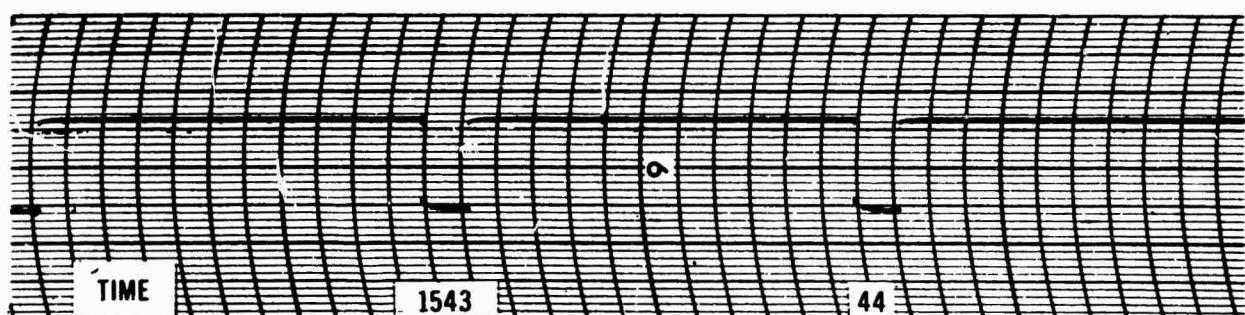
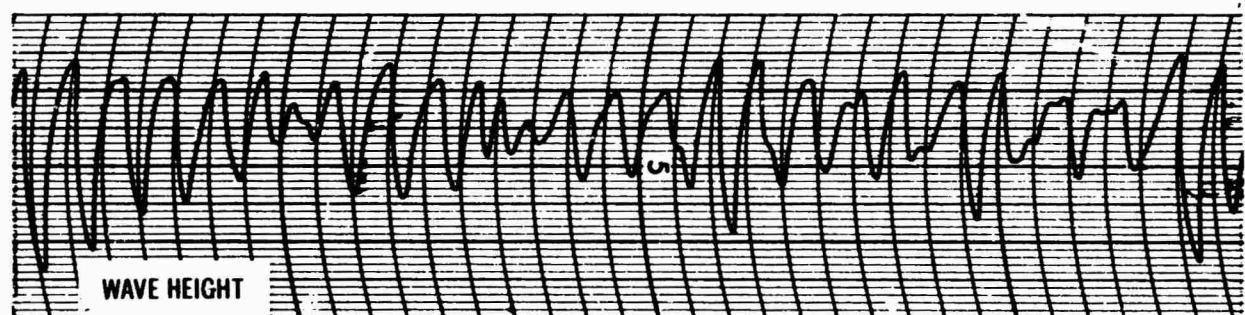
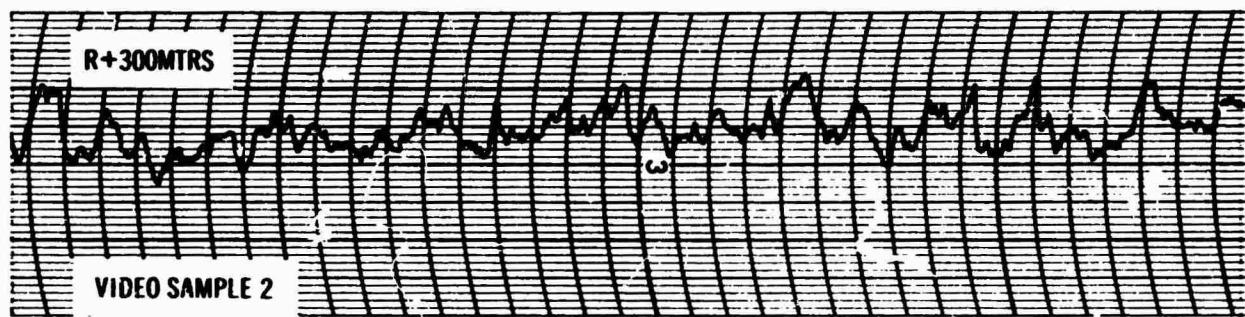
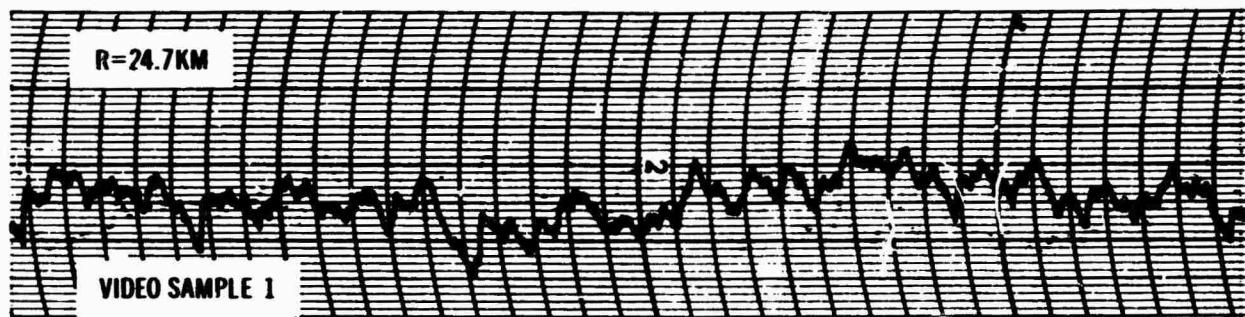


FIG. 2.3 - DATA SAMPLE USING RADAR ANTENNA WITH 2-DEGREE BEAMWIDTH

3.0 THEORY OF OPERATION - SEA STATE ANALYZER

3.1 Technique

The observed correlation between ocean wave periods and fluctuations within radar video noise is utilized as the basis for measurement in the Radar Sea State Analyzer. This requires that the frequency content of the signal waveform of interest, within a specified passband and sampled at a selected range from the radar, be extracted from the broadband signal and noise. A slope detection technique is used to convert this filtered input signal into a train of frequency-dependent pulse widths, and the resultant zero-crossing intervals are then examined for frequency content.

Since the natural ocean wave alternations are neither pure sinusoids nor of precisely uniform duration, an average period value is needed to achieve a reliable, repeatable measurement. Such a value is obtained by having the instrument electronically compute the function:

$$\text{Average} = \bar{x} = \frac{\sum_{i=1}^N x_i}{N}$$

A sample size (N) of ten periods is chosen as (a), large enough to yield statistical relevance to the results, and (b), small enough to yield a reasonable elapsed time between successive measurements. The actual function executed by the instrument becomes then:

$$\text{Average period} = \bar{P} = \frac{\sum_{i=1}^{10} p_i}{10}$$

The useful outputs of the analyzer are:

1. A digital display of the measured average period, expressed in seconds and tenths of seconds.
2. Binary-coded-decimal electrical outputs of this same period information for further computations, analyses, etc. These outputs comprise both a stored value for the most recently

completed computation, and a real-time, changing value.

3. Analog chart recording of the filtered, range selected signal variations as a function of time.

3.2 ELECTRONIC CIRCUIT FUNCTIONS

A block diagram of the device is shown in Fig. 3.1. The input video signals are sampled at the radar pulse-repetition rate and at an equivalent range established by the delay generator. This filtered signal is applied to (1) the analog chart recorder and (2) to a slope detector/bandpass filter where the frequency-dependent pulse train is generated. A decade counter determines when ten periods of the input data have occurred. This counter output pulse drives a flip-flop which alternately enables one of the AND gates; which in turn permits clock pulses to be passed to the active readout module. The alternate gate inhibits pulses to the store module. At transition change time, the pulse shaper resets the appropriate module so that a new count may be commenced.

Clock pulses are generated by a 100 KHZ crystal oscillator and 5 serially connected decade dividers, yielding output pulses at a one-per-second rate.

3.3 CIRCUIT DIAGRAMS

Circuit diagrams of various sub-elements and logic blocks are included in Figures 3.2 through 3.10.

RADAR SEA STATE ANALYZER
BLOCK DIAGRAM

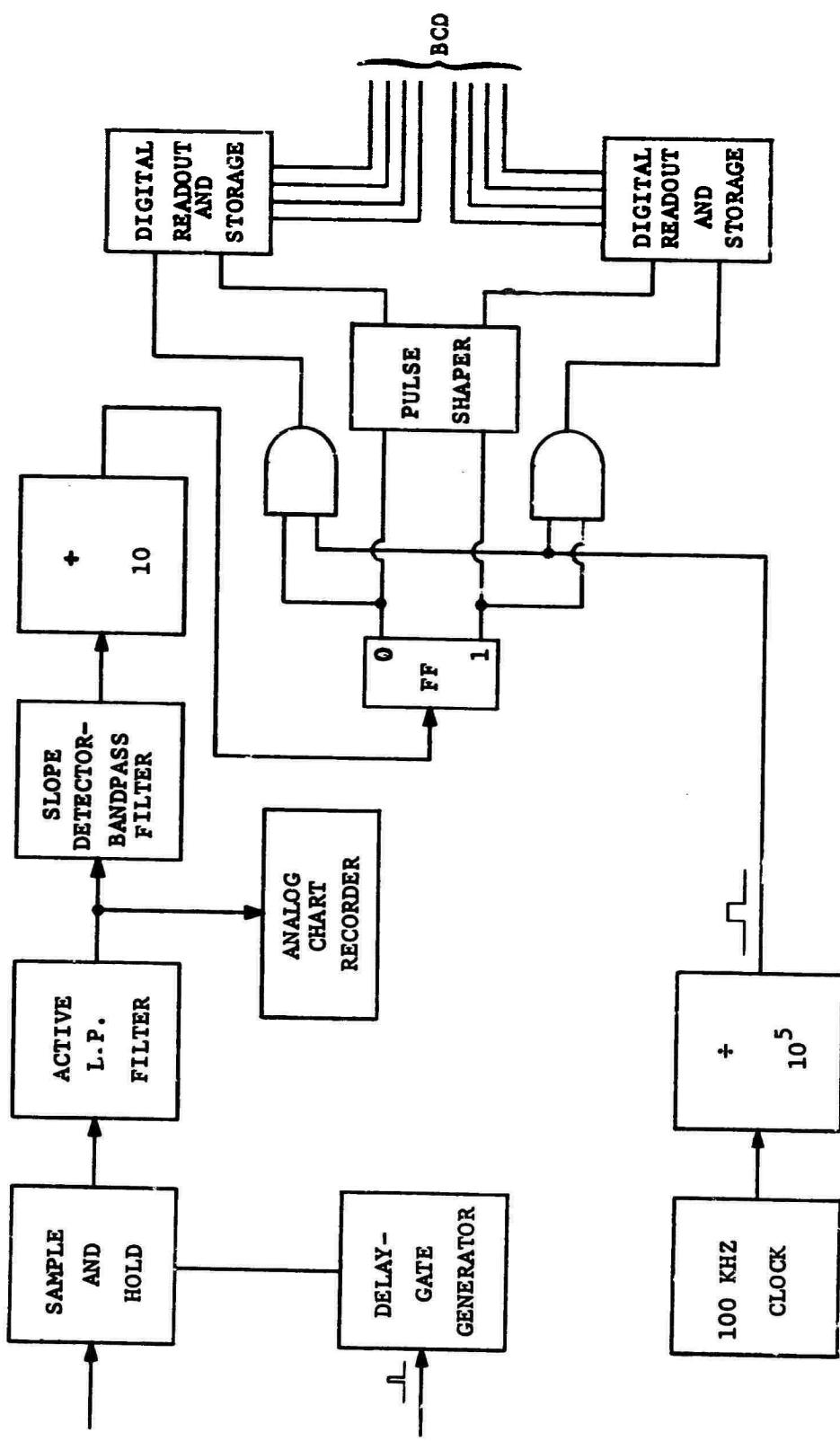


FIGURE 3.1 - BLOCK DIAGRAM

RADAR SEA STATE ANALYZER

CARD NO.1

DUAL REGULATOR

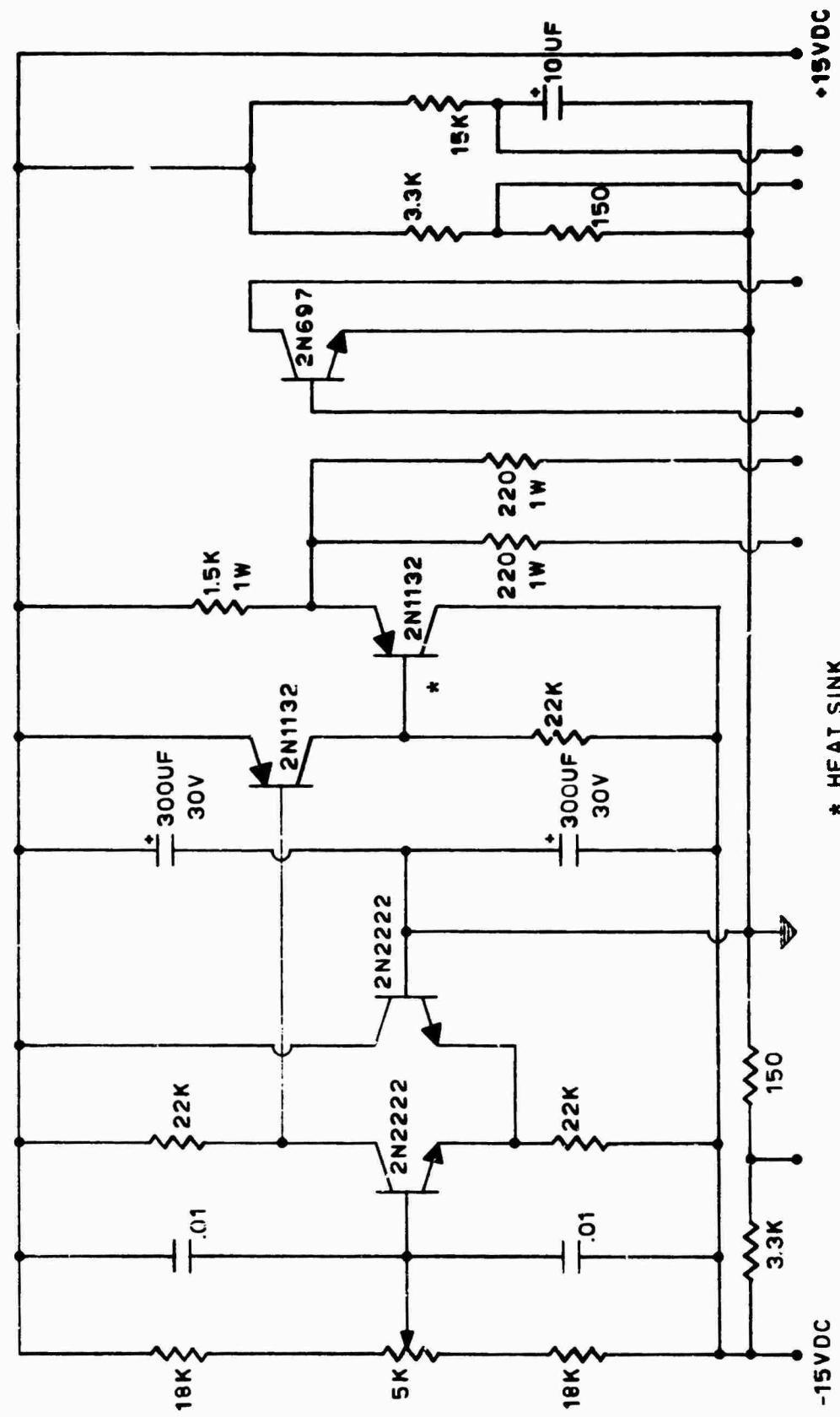


FIGURE 3.2 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER
CARD NO.2
BUFFER AND LAMP DRIVER

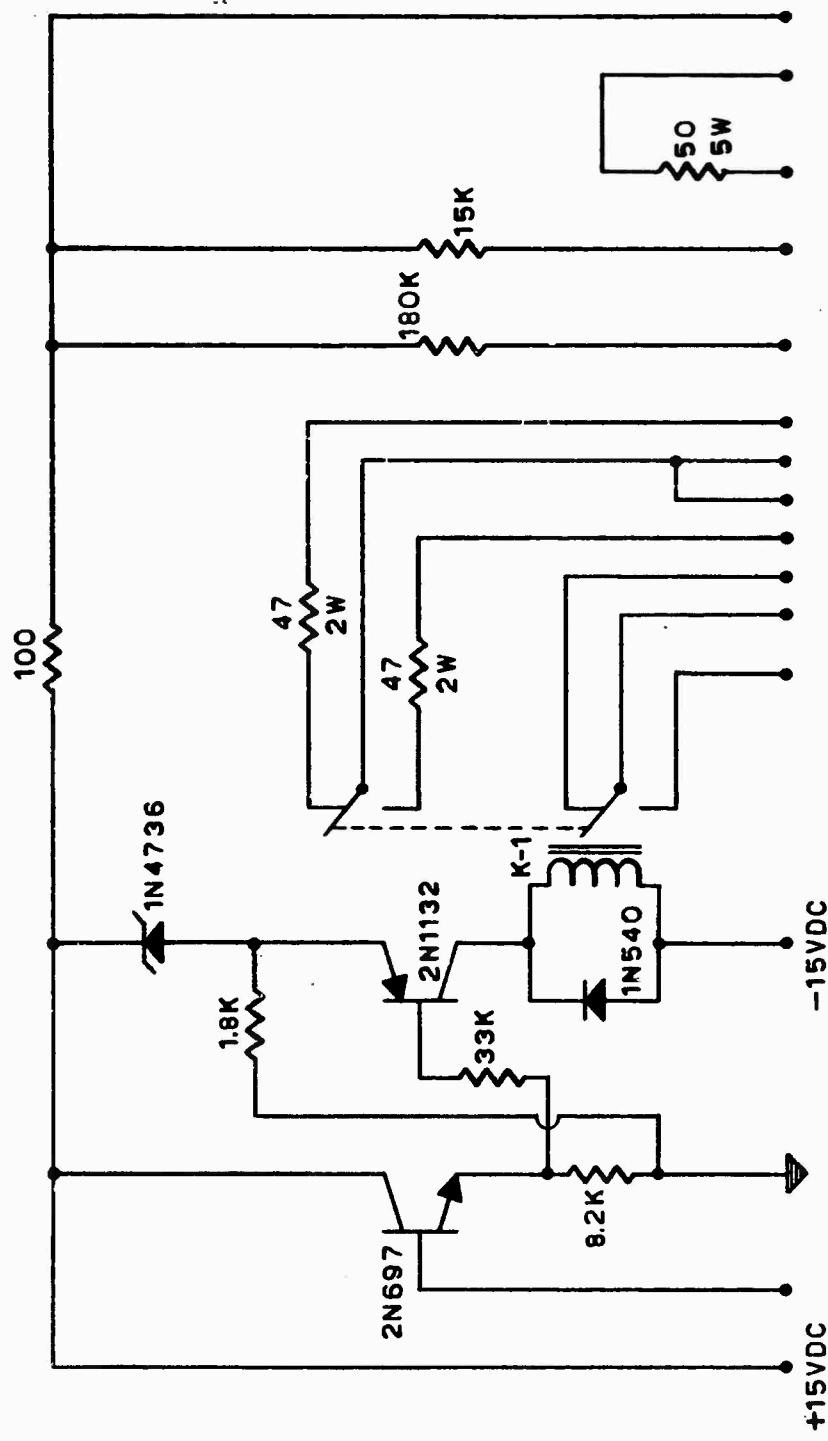
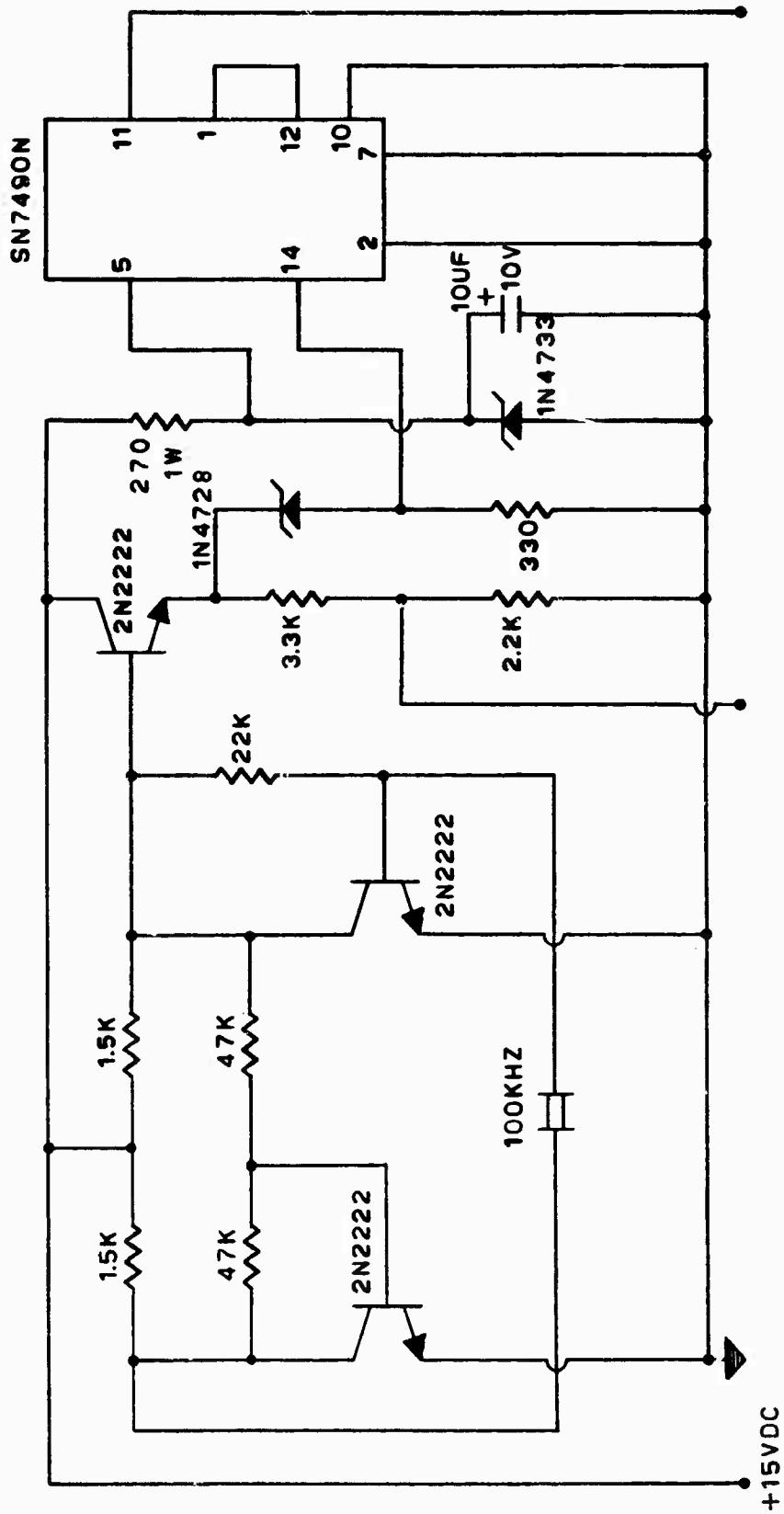


FIGURE 3.3 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER
CARD NO. 3
SYSTEM CLOCK



RADAR SEA STATE ANALYZER
 CARD NO. 4
 10^4 DIVIDER

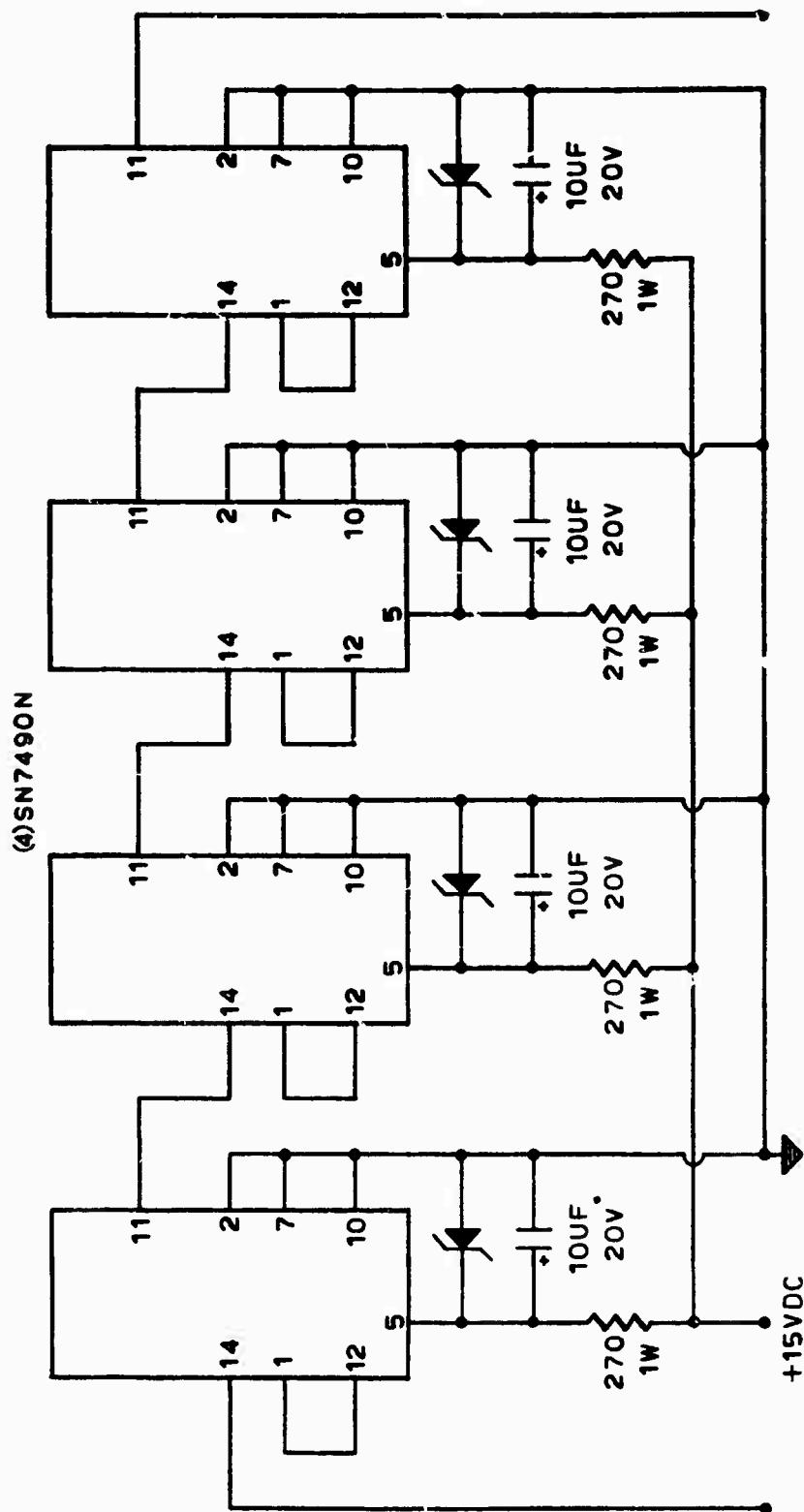


FIGURE 3.5 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER
CARD NO.5
CONTROL LOGIC

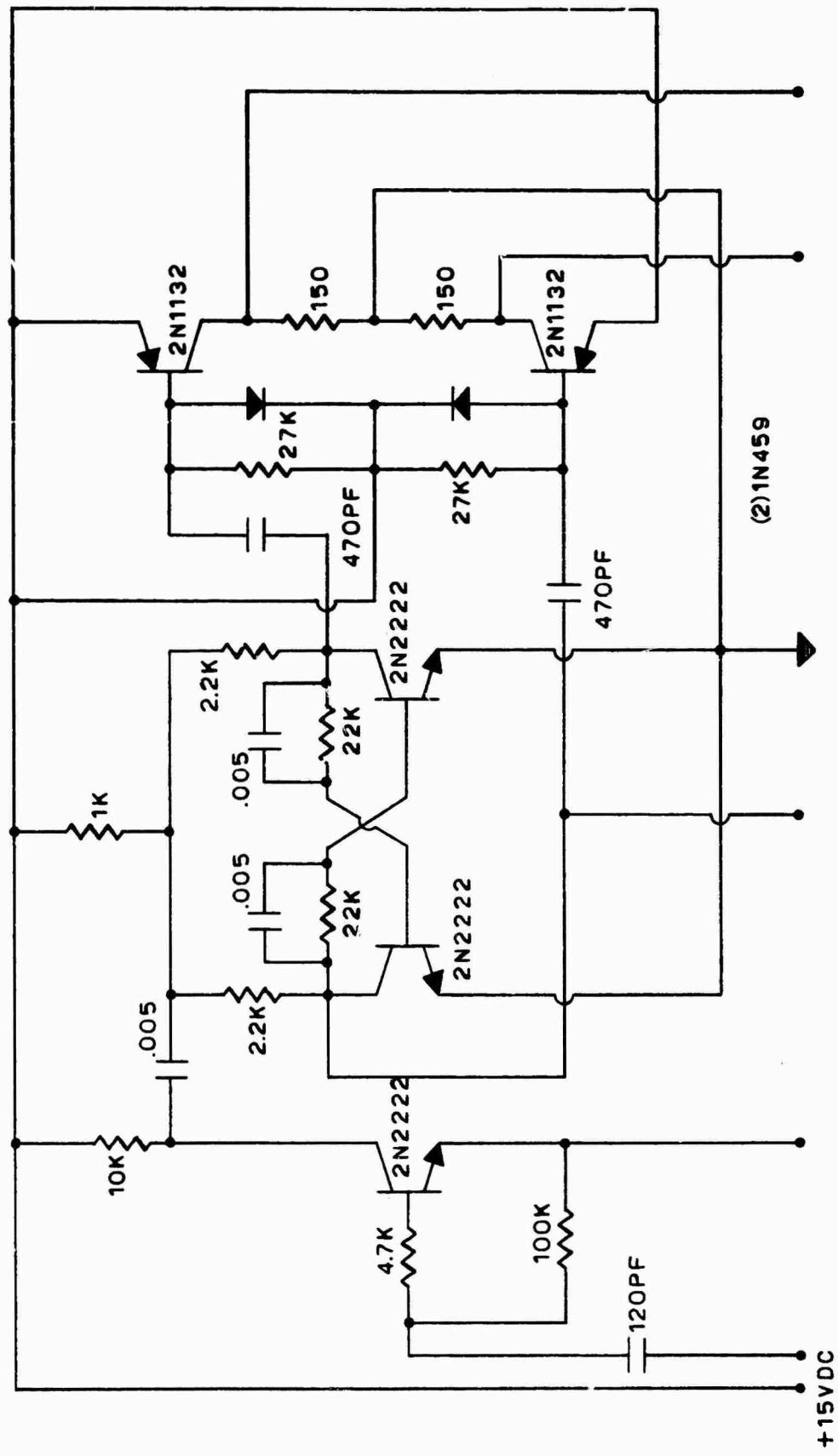


FIGURE 3.6 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER
CARD NO.6
SLOPE DETECTOR AND FILTER

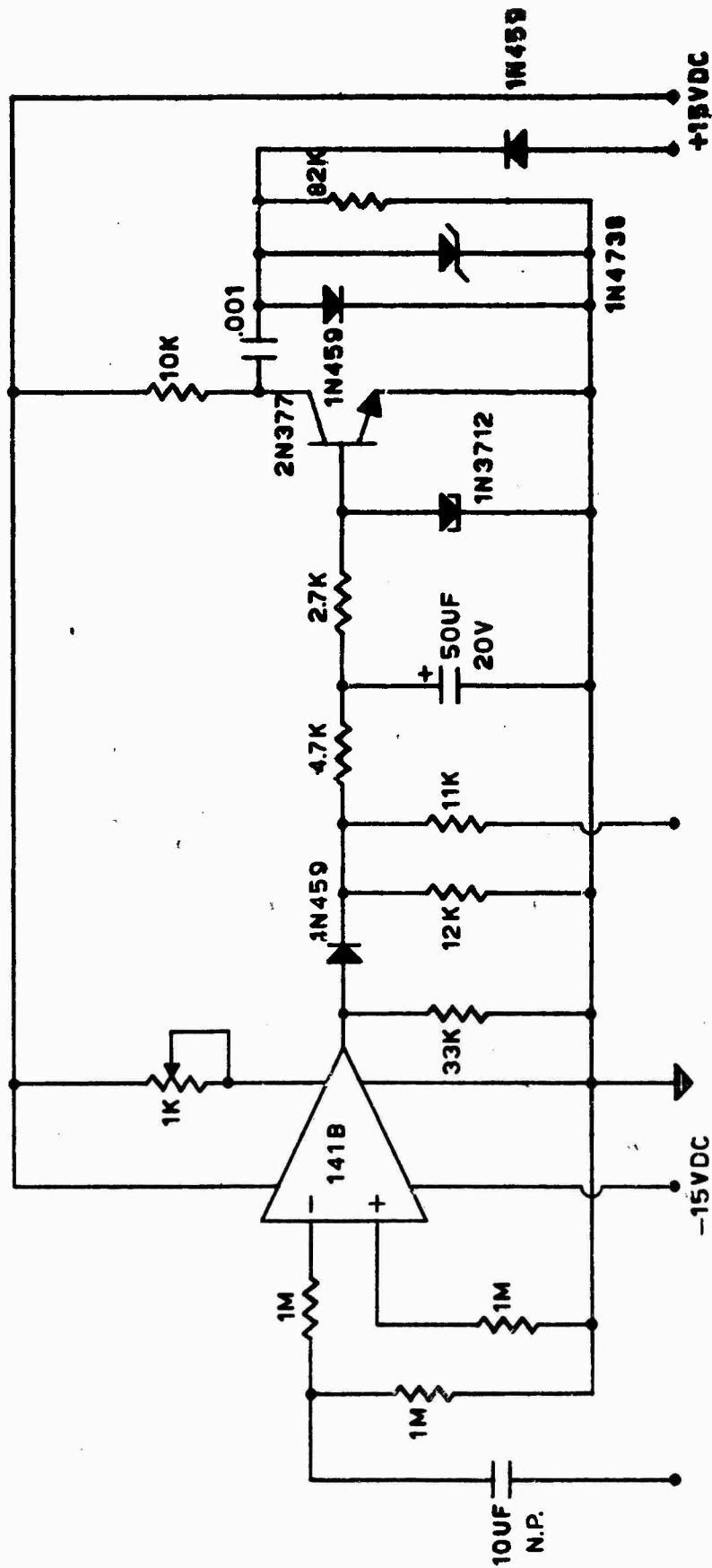


FIGURE 3.7 ♦ SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER
CARD NO.7
GATE AND DELAY GENERATOR

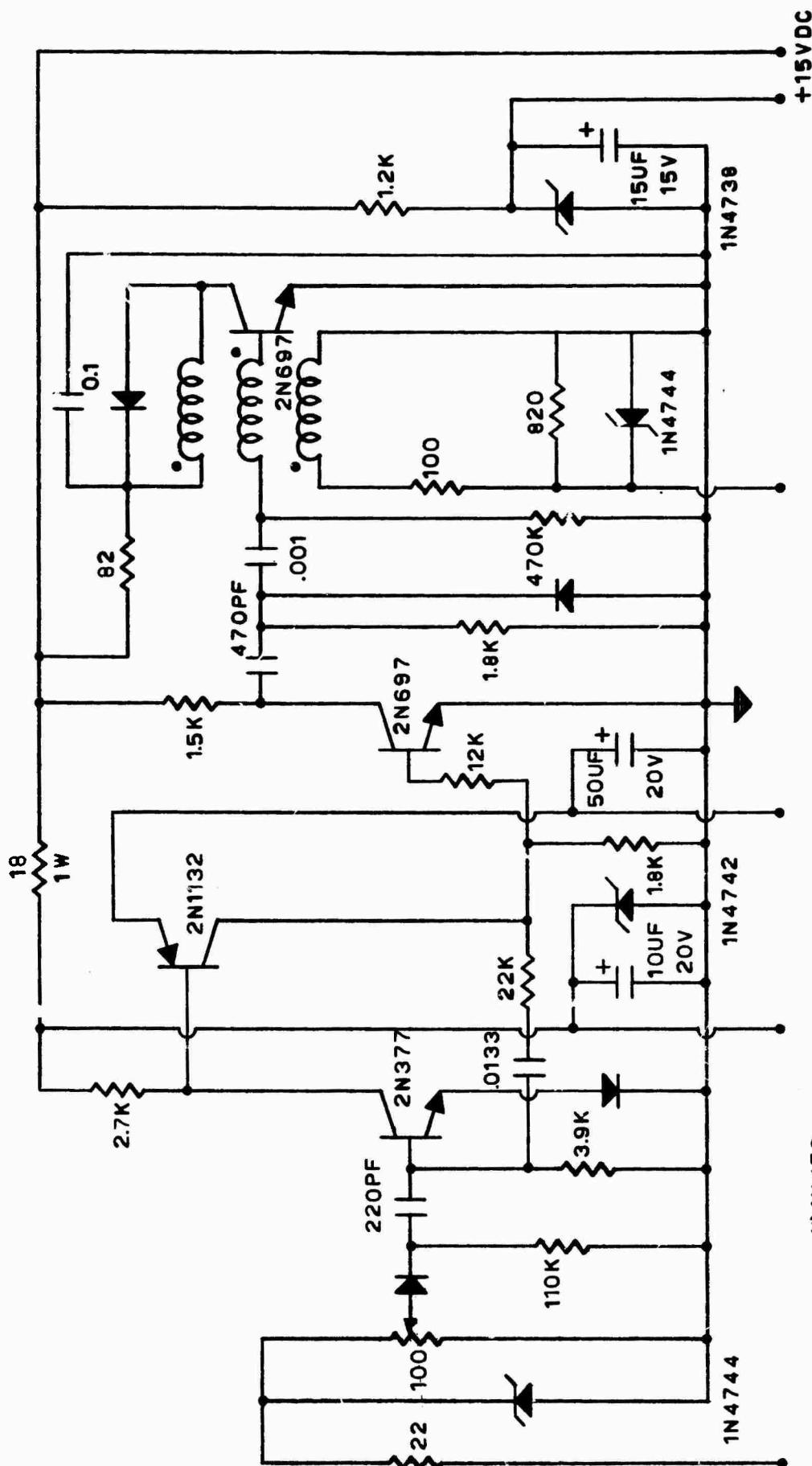


FIGURE 3.8 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER
CARD NO. 6
SAMPLE-HOLD AND ANALOG DRIVER

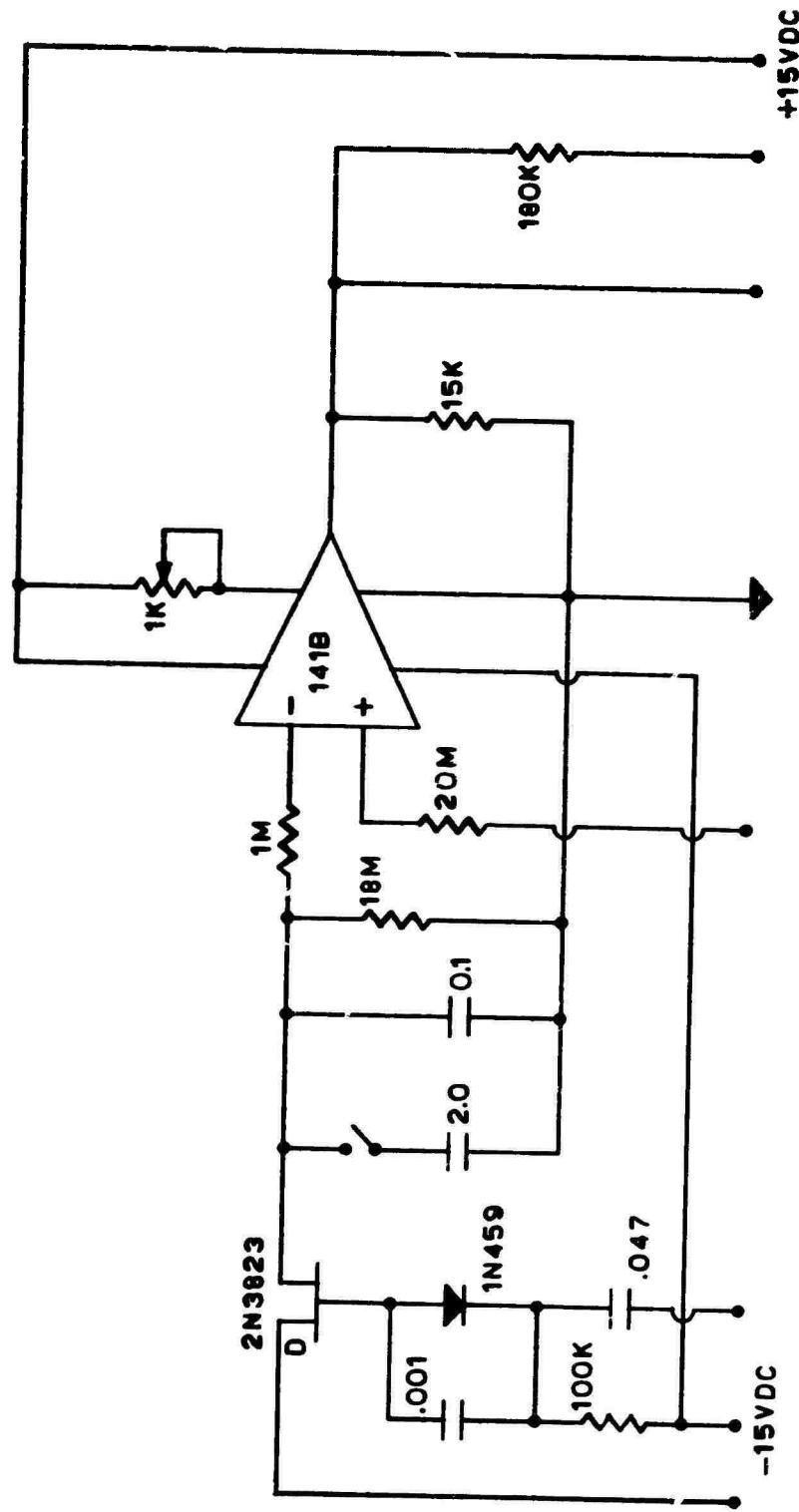


FIGURE 3.9 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER
REGULATOR CONTROL-LV POWER SUPPLY

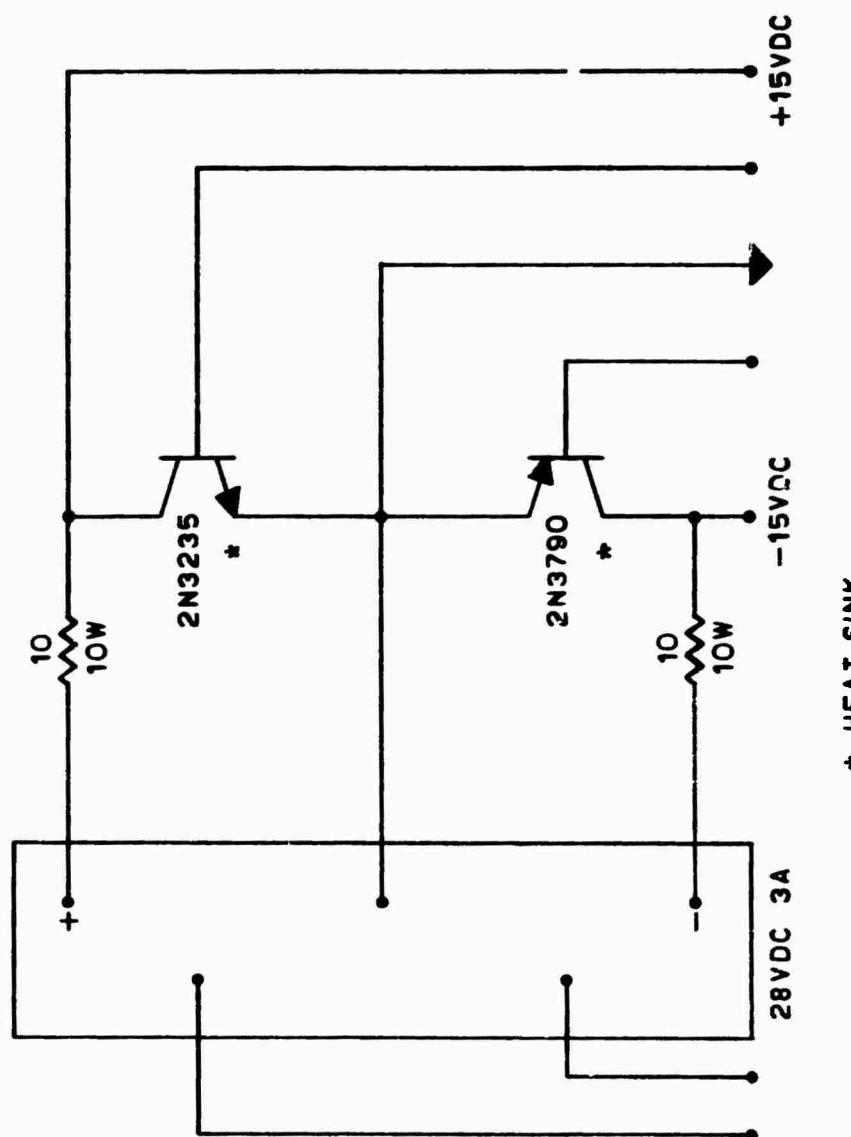


FIGURE 3.10 - SCHEMATIC DIAGRAM

4.0 INSTALLATION

4.1 Inputs

This device is self-contained (see Fig. 4.1) and requires only input signals from the radar with which it is to be used in order to function.

These inputs are applied to BNC connectors on the rear apron, see Fig. 4.2.

Input	Amplitude	Polarity	Duration	Source Impedance
Video	NLT 2V Peak	Positive	N/A	To drive 75 Ω
Trigger	NLT 10V Peak	Positive	NLT 1 μsec	To drive 75 Ω

AC Power 115 VAC, single phase, 50 watts

Dimensions 26" W. x 14" H. x 16" D.

Weight 63 pounds

4.2 Outputs

Electrical outputs from the unit are available on the stripline connectors at the rear on the digital display modules, see Fig. 4.3.

These outputs are BCD, 1248 Positive True Logic, TTL Compatible.

Binary "1" = +5 volts

Binary "0" = +0.2 volts

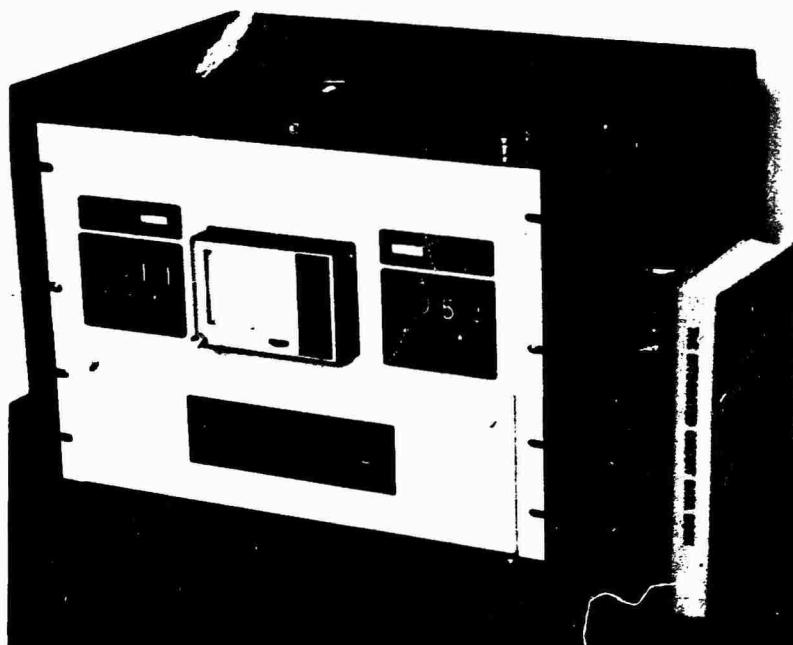


Fig. 4.1 - Radar Sea State Analyzer



Fig. 4.2 - Rear View

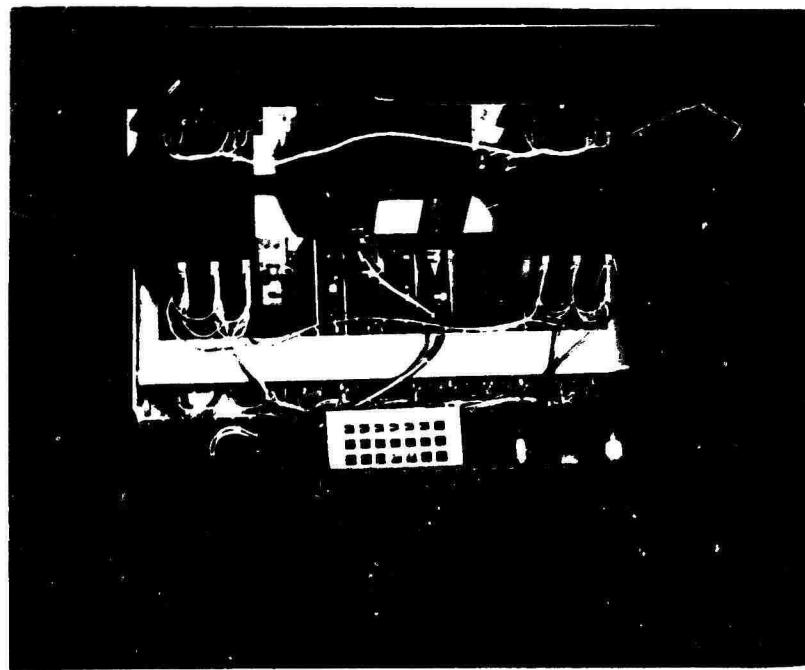


Fig. 4.3 - Top Interior View

5.0 OPERATION AND ADJUSTMENTS

5.1 DIGITAL WAVE PERIOD

There are two sets of digital readouts for wave period in seconds and tenths. These are the front panel displays labeled AVERAGE PERIOD IN SECONDS. One of these is on hold and presents the average wave period most recently computed while the other is computing the period for the new sample. When the new average period is computed, it is held and the two units switch functions with the initial unit going into the compute mode.

5.2 CONTROL PANEL FUNCTIONS

The control panel is located behind the hinged lower cover, (see Fig. 5.1 and 5.2) and contains the following controls, indicators, and test points. The numbers below correspond with the numbers on Figure 5.2.

1. START. The analyzer is turned on by pressing the START button, which becomes illuminated when the unit is on. Successive pressings turn the analyzer off, on etc.
2. DELAY. This control varies the position of the sampling gate, and is adjusted to position the gate at the distance where an analysis is desired.
3. LEVEL. Adjusts the amplitude of the radar video signals applied to the sampling circuitry.
4. RECORDER ON-OFF. Energizes the analog strip chart recorder.
5. EVENT MARK. Places a reference mark on the analog chart recording when pressed.
6. CALIBRATE. Adjusts offset voltage to sample-and-hold circuitry.
7. RESET, LEFT AND RIGHT. Pressing these buttons resets the appropriate display to zero.
8. Δ SLOPE. When illuminated, indicates that a zero-crossing in the input data has occurred.
9. PERIODS COUNTED. Displays the number of periods counted in a particular computing sequence.
10. BNC TEST POINTS.
 - A. GATE. Allows oscilloscope monitoring of the sample gate position.
 - B. SYNC. Provides synchronizing pulse to a monitor oscilloscope.

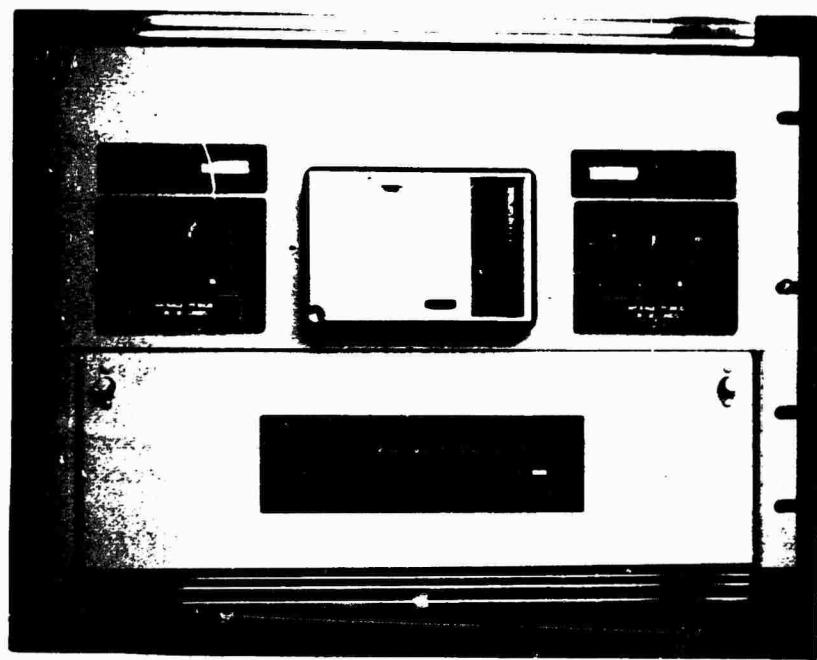


Fig. 5.1 - Front View

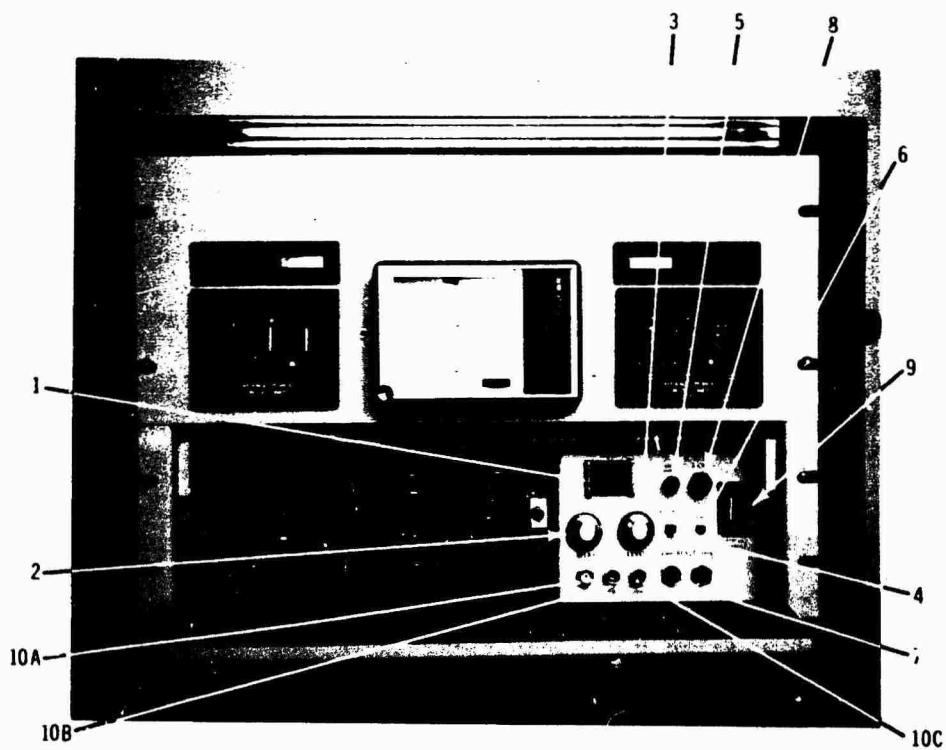


Fig. 5.2 - Front View, Control Panel Exposed

C. VIDEO. Allows oscilloscope monitoring of the radar video signals applied to the analyzer.

5.3 ADJUSTMENT AND OPERATION PROCEDURE

A suggested procedure for initial set-up of this instrument with a given radar system follows:

5.3.1 Preliminary Radar System Adjustments

- (1) With the radar antenna rotating, observe a PPI display to determine the presence of "sea return".
- (2) Note a particular azimuth and range among these signals where a wave period measurement is desired.
- (3) Stop the radar antenna along this selected azimuth.

5.3.2 Analyzer Adjustments and Operating Procedure

- (1) Connect input radar signals to the analyzer as discussed in Section 4.
- (2) Connect a dual-trace oscilloscope to the GATE and VIDEO test points. Connect synchronizing input to the oscilloscope to SYNC test point.
- (3) Turn analyzer ON by pressing START button. Disregard any readings on the display modules.
- (4) Turn recorder switch to OFF.
- (5) Turn LEVEL control full CCW (minimum dial reading).
- (6) Adjust the oscilloscope sweep speed and vertical inputs to display simultaneously (a) the video input encompassing the distance to the "sea return" of interest, and (b) the GATE generated by the analyzer (video level at test point is unaffected by position of LEVEL control).
- (7) Adjust the DELAY control to position the gate at the same distance as the desired "sea return" analysis point.
- (8) Turn RECORDER switch ON.
- (9) Increase LEVEL control until recorder needle varies approximately ± 5 mm (1 cm peak to peak) as the input data fluctuates. Verify that the SLOPE indicator is alternately illuminated and off as the input varies. This adjustment and check provides the proper input amplitude to the sampling and logic circuitry.

- (10) RESET both left and right modules. The PERIODS COUNTED display should begin to register an increasing number at a rate determined by the input data - generally, several seconds between changes.
- (11) Observe the operation for several computations and readout transfers to insure that input adjustment is satisfactory. Unless sea conditions are changing rapidly, the successive computed periods should remain about constant.
- (12) If a permanent analog record is not desired for a particular sampling, the RECORDER may be turned off. This does not interfere with the digital computation and normal operation will continue.
- (13) When a particular measurement is completed, the unit may be turned off (by pressing START button) and radar antenna rotation resumed. Future measurement requires only stopping antenna, turning on unit and verifying that sample gate is at the desired position.
After any LEVEL or DELAY adjustments, the analyzer should be RESET to insure that computation begins from proper starting point.

6.0 INTERPRETATION OF READOUT

It is assumed that the radar antenna will remain stationary in azimuth and elevation when measurements are being made with the Radar Sea State Analyzer. The proper antenna elevation angle will depend upon the height of the antenna above sea level. Assuming that the antenna is within a few tens of feet above sea level, an elevation angle near zero degrees should be satisfactory. This is not a critical adjustment and can be chosen within reasonable tolerances. However, the same elevation angle should be used each day in order to compare signal amplitudes from day to day.

6.1 DIGITAL WAVE PERIOD

The wave period in units and tenths of seconds can be read directly from the front panel of the instrument as described in Section 5.1. If time permits, an average of several readings can be taken to give a longer-term average wave period. Since each digital readout is already an average of ten periods, further averaging by the operator will represent multiples of this number. Simultaneous average wave periods taken from radar data and a wave sensor converge to closer agreement with increased time averaging, as would be expected.

The average wave period in seconds can be used to determine the wavelength in feet and the wave velocity in knots with the aid of the graphical presentation of the theoretical relationship between wave lengths, velocities, and periods of wind-driven gravity waves in deep water, Figure 6.1, Bigelow and Edmondson [51]. A copy of this graph is attached to the instrument. As an illustration of the use of the graph, an observed average wave period of 10 seconds gives approximately a wavelength of 500 ft and a wave velocity of 30 knots.

6.2 ANALOG CHART READOUT

An analog chart readout is provided to aid the user in estimating relative wave heights, Figure 6.2. However, it also provides a permanent record that can be retained if such is desired. The wave period for a specific chart recorded sample can then be analyzed in other ways, if necessary. For example, rates-of-change of wave period for a particular time interval may be computed. The analog chart presents the same data that are used by the digital

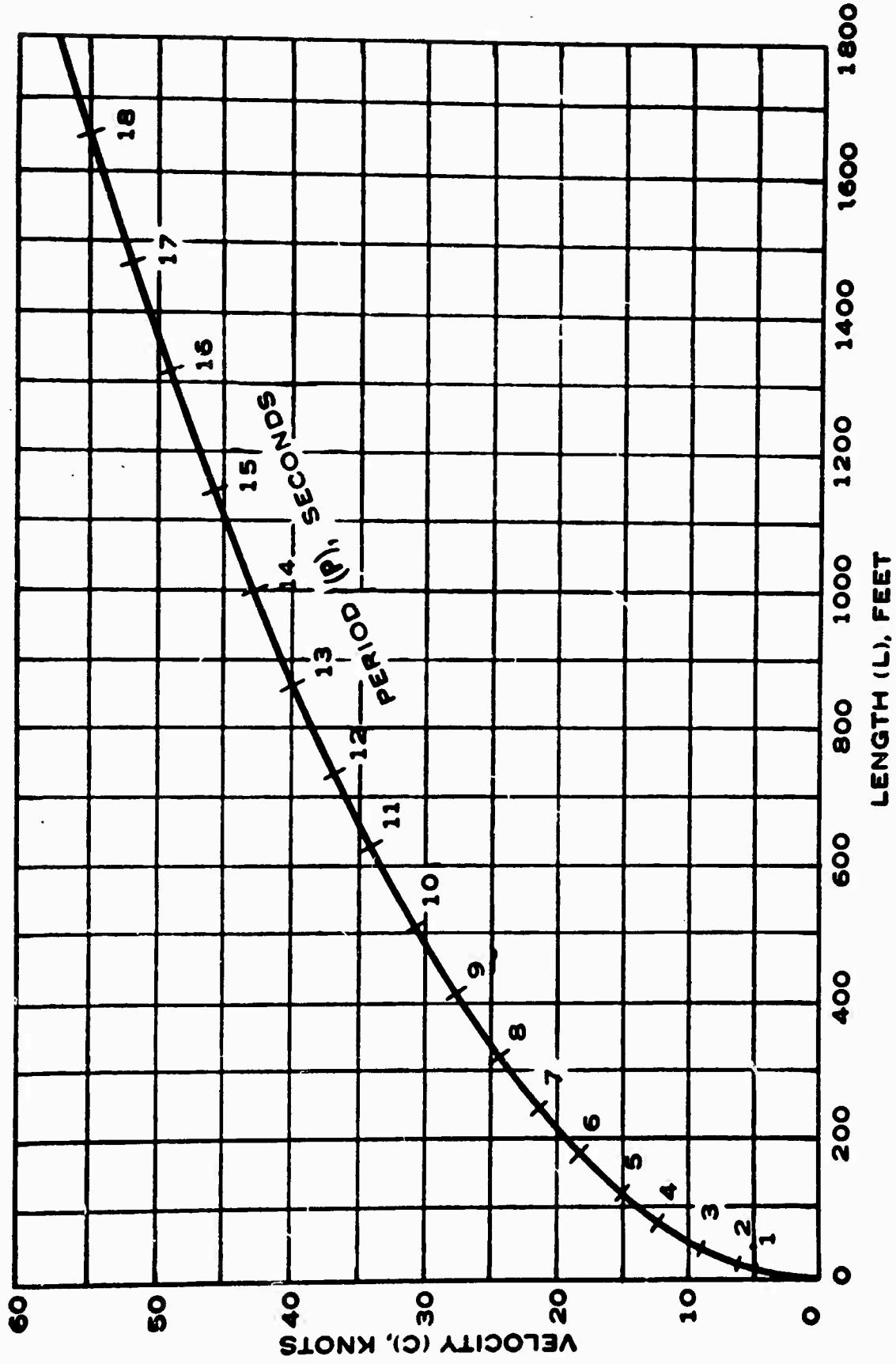


FIG. 6.1 - Graphical presentation of the theoretical relationship between wave lengths, velocities, and periods in deep water.

wave period computer to calculate the wave period in real time. Assuming that the sea state analyzer is turned on and off at certain intervals of time in order to obtain and record the sea conditions, then on and off date and time marks may be entered on the chart to show when the data were taken.

Since the signal amplitude is a function of wave height, radar parameters, antenna azimuth with respect to the direction of the waves, wind speed and direction, and analyzer adjustments, all of these will have to be considered in estimating wave height from the amplitude of the recorded signals. Some of these variables can be greatly reduced or eliminated by standardizing operating procedures. If the antenna is directed upwind, the primary variable that will affect the estimation of wave height from the signal amplitude will be wind speed. For a given wave height, the radar signal amplitude will be greater when the wind is increasing, or strong and steady, than when it is decreasing. Also, the relationship between signal amplitude and wave height is non-linear. The signal amplitude rises rapidly with increasing wave height up to a few feet and then shows a slow increase in amplitude if the waves continue to grow. However, if radar and analyzer adjustments are unchanged, increasing signal amplitude corresponds to increasing wave height.

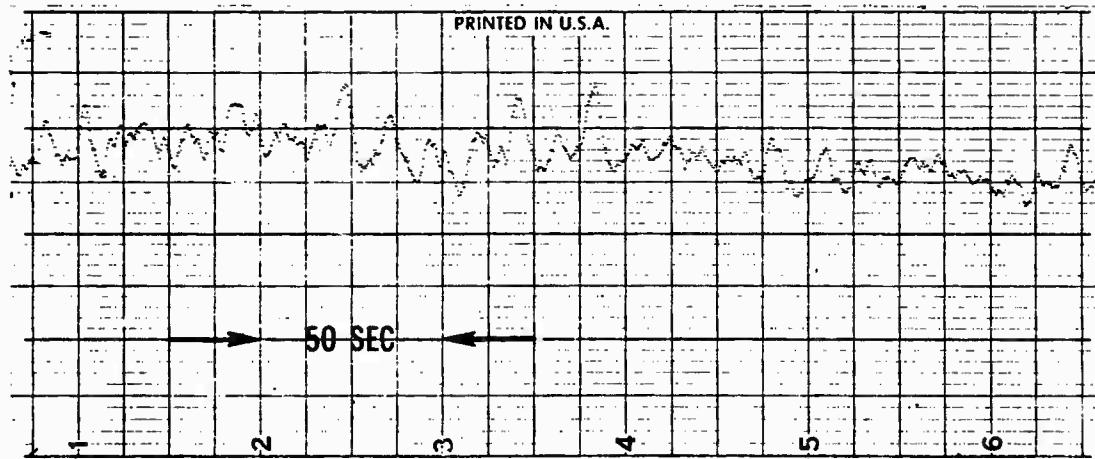


FIG. 6.2 - ANALOG CHART RECORD

7.0 BIBLIOGRAPHY AND REFERENCES

- [1] Navy, U.S., Oceanographic Office, 1952, "Sea and Swell Observations", Hydrographic Office Observers Manual, No. 828-6270.
- [2] Morrow, C.M., 1964, Ocean Wave Profiling Radar System, NRL Report 6052, Tracking Branch Radar Division, U.S. Naval Research Laboratory, Wash. D.C., April.
- [3] MacDonald, F.C., 1957, Characteristics of Radar Sea Clutter Part 1 - Persistent Target-Like Echoes in Sea Clutter, Wave Propagation Branch Electronics Division, Naval Research Laboratory, Wash., D.C., March.
- [4] Marks, Wilbur, 1964, The Application of Airborne Radar Backscatter to Measurement of the State of the Sea, Report No. 64-17, Oceanics, Inc., New York, August.
- [5] Freedman, J., M.M. Kessler, V.L. Lynn, D.A. McKee, W.W. Ward, 1954, Comparative Performance of 10-CM and 70-CM Radar Over the Sea, Technical Report No. 56, Mass. Institute of Technology, Lincoln Laboratory, August, 115pp.
- [6] Brooks, F.E. Jr., H.W. Smith, G.P. Dubose, Jr., 1954, Power Spectra and Statistical Studies of Overwater Signal Strengths For The Golden Gate California Radio Path, The University of Texas, July, 132pp.
- [7] Hicks, B.L., N. Knable, J.J. Kovaly, G.S. Newell, J.P. Ruina, 1958, Sea Clutter Spectrum Studies Using Airborne Coherent Radar III, Univ. of Illinois, Urbana, Illinois, Report R-105, May, 31pp.
- [8] Nielson, Don., George Hagn, Louis Rorden, Neal Clark, 1960, An Investigation of the Backscatter of High-Frequency Radio Waves From Land, Sea Water, and Ice, Stanford Research Institute, California, Final Report, May, 141pp.
- [9] Brooks, F.E. Jr., 1957, Final Report of Radio Results for 1955 Gulf of Mexico Propagation Tests, The University of Texas, March, 27pp.
- [10] Wagner, N.K., J.R. Gerhardt, 1957, Final Report of Meteorological and Oceanographic Results for 1955 Gulf of Mexico Propagation Tests, The University of Texas, March, 34pp.
- [11] Beard, C.I., 1960, Coherent and Incoherent Scattering of Microwaves From the Ocean, Electronic Defense Laboratories, Mountain View, California, July, 72pp.
- [12] Long, M.W., R.D. Wetherington, J.L. Edwards, A.B. Abeling, 1965, Wavelength Dependence of Sea Echo, Final Report, Georgia Institute of Technology, Atlanta, Georgia, July, 79pp.

- [13] Schule, J.J., K. Terada, H. Walden, G. Verploegh, 1962, Methods of Forecasting the State of Sea on the Basis of Meteorological Data, Tech. Note No. 46, World Meteor. Organization, Geneva, Switzerland, 35pp.
- [14] The Commission for Maritime Meteorology, 1962, Precipitation Measurements At Sea, Tech. Note No. 7, World Meteor. Organization, Geneva, Switzerland, 18pp.
- [15] M.I.T. Radiation Lab., 1946, Fluctuations in the Return Signals from Random Scatterers (Window, Rain, Sea Echo), M.I.T., Report 773, Appendix II, January, 5pp.
- [16] Kronengold, M., J.M. Loewenstein, G.A. Berman, 1965, "Sensors For The Observation of Wave Height and Wind Direction", Proc. 3rd Natl. Mar. Sci. Sym., Vol. 3, April, pp273-288.
- [17] Kronengold, M., W. Vlasak, 1965, "A Doppler Current Meter", Proc. 3rd Natl. Mar. Sci. Sym., Vol. 3, April, pp237-250.
- [18] Boring, J.G., E.R. Flynt, M.W. Long and V.R. Widerquist, 1957, Sea Return Study, Final Report, Project No. 157-96, Georgia Institute of Technology, Atlanta, Georgia, August, DDC AD-246 180.
- [19] Katzin, M., 1957, "On the Mechanisms of Radar Sea Clutter", Proc. of the I.R.E., Vol. 45, No. 1, January.
- [20] Grant, C.R. and B.S. Yaplee, 1957, "Back Scattering from Water and Land at Centimeter and Millimeter Wavelengths", Proc. of the I.R.E., Vol. 45, No. 7, July.
- [21] Kerr, Donald E., 1951, Propagation of Short Radio Waves, Massachusetts Institute of Technology, McGraw-Hill, pp481-527.
- [22] Kirk, R.L., 1966, Surface Evaluation and Definition (SUEDE) Program, Final Report No. 7067, Optical Systems, Inc., Pasadena, California, December, 117pp.
- [23] Hagn, George, 1962, An Investigation of the Direct Backscatter of High-Frequency Radio Waves From Land, Sea Water, and Ice Surfaces, Final Report II, Stanford Research Institute, Menlo Park, California, May.
- [24] Duntley, Seibert Q., and Catharine F. Edgerton, 1966, The Use of Meteorological Satellite Photographs for the Measurement of Sea State, Final Report, S.Q. Duntley, LaJolla, California, June, 136pp.
- [25] Stutt, C.A., S.J. Fricker, R.P. Ingalls, M.L. Stone, 1956, Preliminary Report on Ground-Wave-Radar Sea Clutter, Technical Report No. 134, Massachusetts Institute of Technology, September, 27pp.

- [26] U.S. Navy Weather Research Facility, 1966, Sea and Swell Observations, Norfolk, Virginia, March, 19pp.
- [27] Camnitz, H.G., and R.R. Rogers, 1965, Project Wave-An Experiment and Theoretical Study of Scattering From Water Waves, Cornell Aeronautical Laboratory, Inc., Buffalo, New York, March, 98pp.
- [28] Clayton, L., H.D. Ivey, and H.H. Teegardin, 1954, Preliminary Study for The Development of A Sea State Meter, Technical Report No. 6, Georgia Institute of Technology, Atlanta, Georgia, October, 18pp.
- [29] Bean, B.R., E.J. Dutton, 1966, Radio Meteorology, National Bureau of Standards Monograph 92, Boulder, Colorado, March, 435pp.
- [30] U.S. Navy Weather Research Facility, 1960, Meteorological Aspects of Radio-Radar Propagation, Norfolk, Virginia, June, 173pp.
- [31] Findlay, A.M., 1968, Sea-Clutter Measurement by Radar-Return Sampling, Naval Research Laboratory, Washington, D.C., NRL Report 6661, February 20pp.
- [32] Cox, C., 1967, The Relation of Backscattered Radiation to Wind-Stress at the Sea Surface, Final Report, Scripps Institution of Oceanography, La Jolla, California, February, 25pp.
- [33] Snyder, R.B., 1965, Radar Determination of Sea State, U.S. Navy Weather Research Facility, Norfolk, Virginia, NWRF Technical Paper No. 20-65, November, 14pp.
- [34] Roberts, W.L., 1964, Study of Waves in a Small Tank, U.S. Naval Research Laboratory, Washington, D.C., NRL Report 6097, July, 10pp.
- [35] Myers, G.F., 1958, High-Resolution Radar Part IV - Sea Clutter Analysis, U.S. Naval Research Laboratory, Washington, D.C., NRL Report 5191, October, 22pp.
- [36] Beckmann, P., and A. Spizzichino, 1963, The Scattering of Electromagnetic Waves from Rough Surfaces, The MacMillan Company, New York, New York, 503pp.
- [37] Defense Documentation Center, 1966, Radar Sea Clutter Bibliography (Supplement), Defense Supply Agency, Alexandria, Virginia, AD-373 700, June, 81pp.
- [38] Ghose, Dr. S.C., 1961, Radar Sea Clutter, E.M.I. Electronics Limited, Hayes, Middlesex, England, Report No. DP.1025, DDC AD 328 919, August, 164pp.
- [39] Davies, H. and G.G. MacFarlane, 1946, "Radar Echoes from the Sea Surface at Centimetre Wave-Lengths", Proc. Physical Society London, Vol. 58, Nov., pp717-729.

- [40] Skolnik, M.I., 1962, Introduction to Radar Systems, McGraw-Hill Book Company, New York, N.Y., p 532.
- [41] Transactions of the 1959 Symposium on Radar Return Part 2, 1960, University of New Mexico, 11-12 May 1959, NOTS TP 2339, January, 266pp.
- [42] U.S. Naval Air Development Center, 1962, Radar Polarization Characteristics of Seaborne Targets and Sea Return at Mt. Cadillac, Maine (U), Phase Report No. NADC-EL-6219, Johnsville, Pennsylvania, DDC AD 329 393, April, 20pp.
- [43] Long, M.W., 1965, "On the Polarization and the Wavelength Dependence of Sea Echo", IEEE Transactions, September, p 749-754.
- [44] Pidgeon, V.W., 1968, "Doppler Dependence of Radar Sea Return", J. Geophysical Research, Vol. 73, No. 4, February 15, p 1333-1341.
- [45] Monahan, E.C., 1968, "Sea Spray as a Function of Low Elevation Wind Speed", J. Geophysical Research, Vol. 73, No. 4, February 15, p 1127-1137.
- [46] Fuller, I.W., J. Jackson, and W.L. Roberts, 1968, Radar Sea Clutter - NRL Measurements, Naval Research Laboratory, Washington, D.C., Report No. 5310-57, April, 12pp.
- [47] Fuller, I.W., 1961, High-Resolution Radar - Part V - Project Cutwater, August-September 1960, Naval Research Laboratory, Washington, D.C., Report No. 5651, June, 22pp., DDC AD 343-096.
- [48] Fuller, I.W., 1961, High-Resolution Radar - Part VI - Project Cutwater, November-December 1960, Naval Research Laboratory, Washington, D.C., Report No. 5653, June, 25pp., DDC AD 342-365.
- [49] Fuller, I.W., 1961, High-Resolution Radar - Part VII - Project Cutwater, January-March 1961, Naval Research Laboratory, Washington, D.C., Report No. 5654, June, 29pp., DDC AD 343-099.
- [50] Bass, F.G., I.M. Fuks, A.I. Kalmykov, I.E. Ostrovsky, and A.D. Rosenberg, 1968, "Very High Frequency Radiowave Scattering by a Disturbed Sea Surface", Parts 1 and 2, IEEE Transactions on Antennas and Propagation, Vol. AP-16, No. 5, September, p 554-568.
- [51] Bigelow, H.B., and W.T. Edmondson, Wind Waves at Sea, Breakers and Surf, U.S. Navy Hydrographic Office, Washington, D.C., H.O. Pub. No. 602, 1947.
- [52] Kinsman, B., Wind Waves, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1965.

- [53] Sverdrup, H.U., Oceanography for Meteorologists, Prentice-Hall, Inc., New York, 1942.
- [54] Hiser, H.W., G.F. Andrews, and C.L. Courtright, Relations Between Radar Sea Clutter and Existing Local Weather Conditions (U), 20 April 1966 to 20 February 1967, Final Report to Naval Air Systems Command, March 1967.
- [55] Blackman, R.B., and J.W. Tukey, The Measurement of Power Spectra, Dover Publications, Inc., New York, 190p, 1959.
- [56] Schooley, A.H., 1956, "Some Limiting Cases of Radar Sea Clutter Noise", Proc. IRE, Vol. 4, No. 8, p 1043-1047.
- [57] Hiser, H.W., and G.F. Andrews, Relations Between Radar Sea Clutter and Existing Local Weather Conditions (U), 1 July 1967 to 30 June 1968, Final Report to Naval Air Systems Command, September 1968.
- [58] Andrews, G.F., 1968, "Spectral Measurements of Video Signals from Meteorological Radars", Proc. 13th Radar Met. Conf., American Meteorological Society, Boston, pp59A-59E.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Radar Meteorological Laboratory Rosenstiel School of Marine and Atmospheric Sciences University of Miami, Miami, Florida 33149		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP n/a
3. REPORT TITLE RADAR SEA STATE ANALYZER (U)		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report 15 May 1968 to 15 August 1969		
5. AUTHOR(S) (Last name, first name, initial) Andrews, George F., and Hiser, Homer W.		
6. REPORT DATE December 1969		7a. TOTAL NO. OF PAGES 35
8a. CONTRACT OR GRANT NO. N00019-68-C-0393		9a. ORIGINATOR'S REPORT NUMBER(S) B8765-1
8b. PROJECT NO. c. d.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) none
10. AVAILABILITY/LIMITATION NOTICES Distribution of this report is unlimited.		
11. SUPPLEMENTARY NOTES None		12. SPONSORING MILITARY ACTIVITY Naval Air Systems Command Department of the Navy
13. ABSTRACT <i>The theory and description of a Radar Sea State Analyzer are presented. Installation, operation, adjustments, and readout interpretation instructions are also included. The instrument is the product of three years of research to obtain sea state information by using an existing radar as the remote sensor. This device is an attachment to the radar and examines the "sea return" signals at a selected range within the limits of the radar horizon. The outputs are available in digital and analog form. It is small in size and uses modern semi-conductor techniques, integrated circuits, etc. to achieve stability, accuracy and reliability.</i>		

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radar Meteorology Sea Clutter Sea Return Video Spectrum Analysis Sea State Sea Environmental Sensors Remote Sensors						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (corporate author) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, &c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (either by the originator or by the sponsor), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain CCP's of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through _____."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through _____."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through _____."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (paying for) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.